NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

FROM GREASEBOARDS TO GIGABYTES: A COMPARATIVE ANALYSIS OF NAVAL AVIATION AND COMMERCIAL AIRLINES MAINTENANCE SCHEDULING METHODS

by

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December, 1995

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*
2. REPORT DATE December 1995.
3. REPORT TYPE AND DATES COVERED Master's Thesis
4. TITLE AND SUBTITLE FROM GREASEBOARDS TO GIGABYTES: A COMPARATIVE ANAYLSIS OF NAVAL AVIATION AND COMMERCIAL AIRLINES MAINTENANCE SCHEDULING METHODS
5. FUNDING NUMBERS
6. AUTHOR(S) Barnes, Robyn D. and Harding, J. C.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000
8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

In Naval Aviation maintenance organizations, planning and scheduling of preventive maintenance actions tend to be left to ad hoc and traditional methods. The aviation operations exist in a highly dynamic environment; aircraft utilization, configurations, resource constraints and operational requirements change several times a day. To ensure that quality aircraft are available for operations, changes in maintenance schedules must be performed on a continuing, iterative basis, requiring integration of numerous data bases and intensive number crunching.

Though operating in a more stable environment, commercial airlines attempt, as do Naval Aviation squadrons, to optimize aircraft utilization, mission readiness and/or maintenance yield under a set of constrained resources. In order to take advantage of the speed and efficiency related to automated software systems, a few airlines have recently developed and implemented integrated decision support systems (DSS) within their maintenance information systems. This has yielded extraordinary productivity improvements.

In this thesis, the authors show that the implementation of an automated DSS, similar to those used in the airline industry, that could be integrated into the Naval Aviation Logistics Command Information System (NALCOMIS) would maximize resource utility while minimizing the impact of numerous ever-changing constraints. To reduce procurement lead time and minimize development risk and cost, the authors recommend the adaptation of a commercial off-the-shelf aviation-related DSS and provide a possible implementation plan.

14. SUBJECT TERMS Organizational-level maintenance, Depot-level maintenance, Maintenance scheduling, Decision support system, FA-18C, P-3C
15. NUMBER OF PAGES 91
16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

In Naval Aviation maintenance organizations, planning and scheduling of preventive maintenance actions tend to be left to ad hoc and traditional methods. The aviation operations exist in a highly dynamic environment; aircraft utilization, configurations, resource constraints and operational requirements change several times a day. To ensure that quality aircraft are available for operations, changes in maintenance schedules must be performed on a continuing, iterative basis, requiring integration of numerous maintenance data bases and intensive number crunching.

Though operating in a more stable environment, commercial airlines attempt, as do Naval Aviation squadrons, to optimize aircraft utilization, mission readiness and/or maintenance yield under a set of constrained resources. In order to take advantage of the speed and efficiency related to automated software systems, a few airlines have recently developed and implemented integrated decision support systems (DSS) within their maintenance information systems. This has yielded extraordinary productivity improvements.

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ACKNOWLEDGMENT

The authors would like to acknowledge the financial support of Captain Stephen Heilman, USN, Commanding Officer, Naval Aviation Depot Alameda for travel funding to various fleet locations in preparation for this thesis. Also, the authors greatly appreciate the technical support from Ms. Sandra Gantt and Mr. Douglas Gray of SABRE Decision Technologies, Inc. for providing valuable information and a copy of the DockPlan software module for examination and preliminary testing.

The authors would also like to thank Rear Admiral Donald Eaton, USN (Retired) and Professor Keebom Kang for their assistance and support during the thesis process. Lastly, the authors extend their appreciation to the aviation maintenance managers from the numerous fleet squadrons which were interviewed. Their candid insights, frank opinions and suggestions proved to be invaluable in performing this thesis.

I. INTRODUCTION

A. BACKGROUND

Aircraft maintenance, in both military and commercial sectors, comprises a large portion of their operational resources. Despite the importance of scheduling maintenance in Naval Aviation Maintenance organizations, planning and scheduling of preventive maintenance actions tend to be left to ad hoc and traditional methods. Aviation operations exist in a highly dynamic environment; aircraft utilization, configurations, resource constraints and operational requirements change several times a day. Within this environment, maintenance managers must assimilate much more technical information than before to ensure that only top quality aircraft are being flown.

Under increased pressure to make accurate decisions more quickly and easily, at less cost, commercial airlines saw the need to develop and improve software-based automated decision support systems to assist in maintenance scheduling. Naval Aviation, a leader in the use of advanced technology to reduce pilot workload while increasing capabilities and effectiveness of aircraft systems, should use this same philosophy involving maintenance scheduling technology.

Historically throughout Naval Aviation, maintenance planning in a squadron has consisted of manual record keeping and planning by a small maintenance staff. Usually, the leader of this staff, a

sagacious maintenance manager known as the "Master Chief," uses his or her experience and learned heuristic patterns to develop a short range maintenance schedule. Even as maintenance and utilization data have been converted over to automated databases and spreadsheets during the past decade, it still requires numerous manual iterations of interrogating the historical database, integrating information and adjusting schedules to meet ever-changing resource constraints. Figures 1 and 2 represent examples of this data, which are typical of those used in fleet squadrons. This process is influenced heavily by the level of experience of the management personnel. It also consumes inordinate amounts of time and manpower, and many times, results in a sub-optimal plan.

This study addresses a significant issue which directly impacts battle force readiness within the Navy. Particularly in light of a dynamic threat environment and an aging aircraft fleet -- now and in the foreseeable future, Navy aircraft squadrons must be able to plan and use their constrained maintenance resources more efficiently. For example, the Aircraft Service Period Adjustment (ASPA) program has had a significant impact on organizational-level maintenance by delaying scheduled depot level maintenance (SDLM). This has increased the time to complete scheduled organizational-level maintenance due to the fact that the aging aircraft are deteriorating from lack of depot-level preventive maintenance. Until recently, the Navy did not factor in the sailors' labor cost in its budget; this is no longer the case with today's reduced budget. The fleet is expected to do more with less people

PATROL WING   DAILY AIRCRAFT STATUS REPORT

PATROL SQUADRON   JULIAN: 5241   DATE: 29-AUG-95

MODEX	BUNO	FMC	PMC	NMC	OUT RRS	AWM	MAD U/D	A/P U/D	Remarks	Daily Hours	Monthly Hours	Hours to Phase	Last Flown
12	161			S		16	U/O	U	Brake Selector Valve		33.0	77.9 B	5228
09	158		S			22	U/O	D	OMEGA, RADAR		7.0	282.8 D	5236
12	158			S		40	D/M	D	#4 RGB Change, #4 Prop Bulkhead, Phase		40.1	37.6 D	5228
16	158	X				10	D/M	U			43.1	256.2 A	5236
15	162	X				22	D/M	U			53.1	227.2 A	5236
16	162				X				PDM JAX		10.8	303.8 D	5235
22	157		S			35	U/O	U	DMTU A		65.7	1.0 D	5236
24	157	X				28	U/O	U			0.9	90.1 A	5223
39	161				X							137.8 D	5104
07	159		S			32		U	Barbers Point, ALR 66	4.7	30.5	303.3 D	5240
87	161			M		7	U/O	D	#2 PROP DOMEPIN, FCF #1 RGB CHANGE		0.0	11.2 C	5207
	Totals:	3	3	4	2	212					279.5		

Weekly AMRR Inputs (thru 2400 Tue)	
F/Hours:	
Canns:	
MC:	FMC
AK0:	AK7

Aircraft Readiness (to date this month)	
MC: 53.6%	FMC: 37.6%
FLTS: 66	F/HRS: 279.5
CANN S: 35	

Released:

Figure 1. Example of a Squadron Status Report.

MODEX	BUNO	FMC	PMC S/M	NMC S/M	AUTO PILOT	# AWM	APS 134 / APN 234	REMARKS	LOC	DAILY F/HRS	MONTHLY FLT HRS	HOURS & PHASE	LAST FLOWN
-31	156		S		↓	14	↑ ↑	(K) DCI	WI	0.0	13.7	B 277.1	5234
-32	156		S		↑	25	↑ ↑	(D) ~~Rehe~~ IP-1067	KH	24.8	106.8	231.6	5240
-34	156		S		↑	37	↑ ↑	ENROUTE WII (K) DCI		22.3	157.3	D -2.7	5240
-35	157		S		↑	23	↑ ↑	(D) ARC-94	BN	7.0	120.0	D 165.0	5236
-00	150		S		↑	2	VIP HEAD ↓	(K) HF2 Longwire	WI	0.0	48.0	B 163.2	5235
-01	150	X			↑	6	VIP HEAD ↑		HI	0.0	71.9	B 236.9	5234
-43	152	X			↑	5	N/A		UO	12.7	35.2	D 284.3	5239
-44	153	X			↑	3	N/A		WI	0.0	19.8	B 161.3	5236
TOTALS		3	5			113			TOTAL:	66.8			

Figure 2. Example of a Squadron Status Report.

and funds. If scheduled maintenance is not done at the most optimal time, then these scarce resources will be wasted.

The implementation of an automated decision support system (DSS), similar to those successfully used by commercial airline fleets which incorporates maintenance histories and heuristic rules, has the potential to provide a squadron maintenance manager with a powerful tool that would be more effective in planning the maintenance workload. An iterative interaction with the DSS would be able to drive the planning solution in the optimal direction using sensitivity analysis coupled with simulation methods. This would enable the maintenance managers to effectively develop and manage maintenance planning data; formulate maintenance plans much more quickly and efficiently; and generate various reports to describe and evaluate the squadron maintenance effort. Overall, this system could substantially reduce preventive maintenance costs, and improve combat aircraft quality and availability.

B. OBJECTIVE AND RESEARCH QUESTIONS

This thesis examines the implementation of a software-based automated iterative DSS currently used in the commercial airline industry into the daily management of organizational-level Naval Aviation maintenance functions, exclusive of depot-level requirements. The applicability of this Aircraft Maintenance Operations Planning, Scheduling and Control Software pertains primarily to scheduled maintenance processes and the effects of unscheduled events on these processes.

The primary research questions in this study are:

1. Are there significant differences in how Naval Aviation and commercial aviation schedule preventive maintenance requirements?
2. If there are significant differences, why does each sector apply the methodology they are currently using?
3. What system(s) would be the most beneficial in terms of cost, time, manpower, and utilization of equipment and facilities for Naval Aviation maintenance?
4. If the commercial aviation maintenance scheduling program is found to be more efficient than the Navy method, what would be the most effective way to implement it into the Naval Aviation Maintenance Program?

C. SCOPE

This thesis is divided into three parts and focuses primarily on organizational-level maintenance scheduling as performed by shore- and carrier-based Naval Aviation squadrons. First, a valid and supportable comparison has been developed between the scheduling costs and benefits for representative Naval Aviation squadrons (under present methods) and a leading commercial airline. Causes for significant differences are presented.

Second, a valid and supportable comparison has been developed between the scheduling costs and benefits for representative Naval Aviation squadrons under present methods and under methods incorporating an automated DSS.

Third, the study shows that the present scheduling system is inferior to the DSS-supported system in terms of costs and benefits, and reasonable alternatives for reducing costs and enhancing benefits have been analyzed. An implementation plan for the off-the-shelf DSS has been outlined.

D. METHODOLOGY

Data has been obtained from a Navy P-3C squadron based at NAS Whidbey Island, Washington and a Navy FA-18C squadron based at NAS Lemoore, California. Interviews with assigned personnel, examination of historical records and field demonstration of an off-the-shelf automated decision support system were the primary methods of data collection from Naval Aviation activities. Other cost, manpower and utilization data were obtained from the Naval Aviation Maintenance Office's Logistics Management Decision Support System (LMDSS) database and the Navy Comptroller's Office. Data on commercial airline maintenance actions and the off-the-shelf decision support system have been obtained through interviews with personnel from SABRE Decision Technologies personnel in Dallas, Texas and United Airlines in San Francisco, California.

Upon completion of data collection, baselines were established for variables which could affect the comparability of costs and benefits to provide a valid comparison basis.

E. THESIS ORGANIZATION

Chapter II compares the commercial and Naval Aviation Maintenance scheduling methods. Chapter III compares the scheduling costs and benefits between these two methods. Chapter IV analyzes the maintenance scheduling costs and benefits. Chapter V discusses the implementation of an organizational-level maintenance decision support system into P-3C and FA-18C aviation squadrons. Chapter VI summarizes the conclusion and recommendations.

II. COMPARISON OF MAINTENANCE SCHEDULING METHODS

A. INTRODUCTION

As outlined in Chapter I, Naval Aviation and commercial airlines' maintenance scheduling demands are similar. However, the scheduling methods that each type of organization uses are very different. Even though the Naval Aviation Logistics Command Information System (NALCOMIS) automates most maintenance event information for organizational-level managers, they still depend heavily on pencils, paper, greaseboards and simple spreadsheets to formulate maintenance plans. On the other hand, the commercial airline industry relies on sophisticated decision support software to assist in rapid assimilation of maintenance data to determine optimal courses of action. This chapter will discuss each method in detail and draw comparisons.

1. Types of Aircraft Maintenance

Aircraft maintenance within Naval Aviation and commercial airlines can be classified by two different categories -- corrective and preventive maintenance. Corrective maintenance consists of the "unscheduled actions accomplished, as a result of [system or component] failure, to *restore* a system to a specified level of performance." Preventive maintenance, on the other hand, is best defined as "the scheduled actions accomplished to retain a system at a specified level of performance by providing systematic inspection,

detection, and/or prevention of impending failures" (Blanchard, 1986, p. 393). This thesis primarily focuses not on corrective maintenance, but on the preventive maintenance aspect. Because of the scarcity of resources, such as time, manpower, and funding, the proper and timely performance of preventive maintenance actions on aircraft is necessary to optimize system reliability, availability and safety.

Additionally, maintenance actions can also be defined by the three levels of maintenance -- organizational, intermediate and depot. Organizational-level maintenance is normally performed by an operating unit in support of its own operations. These maintenance functions generally include:

a. Visual inspections (both conditional and periodic);
b. Equipment servicing, cleaning and minor adjustments;
c. Aircraft handling;
d. On-aircraft corrective maintenance;
e. On-aircraft preventive maintenance;
f. Incorporation of technical directives; and
g. Record keeping and reports preparation.

Normally, intermediate-level maintenance is performed by remote or co-located organizations with technicians performing more in-depth inspections and repairs than organizational-level technicians; this requires specialized training, skills and support

equipment. Involved in the repair of system components, modules or assemblies, their functions generally include:

a. Corrective and preventive maintenance on aircraft system components;
b. Calibration of support equipment;
c. Major adjustment and servicing of components;
d. Manufacture of selected components, liquids and gases;
e. Component processing;
f. Provide technical assistance to organizational-level maintenance personnel; and
g. Perform on-aircraft maintenance when required.

Located in fixed facilities, depot-level maintenance is largely performed in assembly-line fashion, involving highly skilled specialists in key areas. Depot-level maintenance includes the following functions:

a. Overhaul of aircraft;
b. Rework and repair of components and support equipment;
c. Incorporation of technical directives;
d. Modification of aircraft and support equipment;
e. Special structural inspections;
f. Manufacture or modify parts or kits;

g. Technical and engineering assistance; and
h. Calibration of support equipment (CNO, 1995, Vol. I, para. 7.2).

2. Maintenance Requirements and Operational Environment

The maintenance concepts of both commercial airlines and Naval Aviation squadrons directly reflect the operating environments in which they exist. Commercial airliners fly predetermined routes, mostly overland, from large airfields. Even overseas airliners maintain flight levels high enough to avoid the corrosive effects of sea spray. Aircraft flight times are relatively easy to predict; flight regimes are relatively stable and are designed to minimize stress on aircraft systems. Maintenance personnel are located in fixed facilities with enough equipment to perform extensive on-aircraft depot level maintenance.

On the other hand, naval aircraft, particularly those which are tactical carrier-based aircraft, fly numerous mission profiles -- such as air combat maneuvering, low-level close air support and anti-submarine attacks -- throughout a single day, subjecting their systems to tremendous stress, just from the catapult launches and shipboard arrestments alone. The complexity of each type of aircraft also plays a large role in defining the preventive maintenance schedule. All naval aircraft, even shorebased maritime aircraft, normally are tasked with missions requiring low flight levels over open saltwater areas, exposing the aircraft to high corrosion

potential. They also operate in different climatic extremes, where scheduled maintenance is sometimes performed on the flight deck or the flight line -- without the benefit of environmentally-controlled hangars and proper support equipment.

Additionally, all Naval Aviation squadrons must retain the capability to operate virtually anywhere in the world, so the organization must be relatively self-supporting; organizational-level technicians assigned to the squadron perform extensive on-aircraft preventive maintenance in addition to corrective maintenance and servicing. While squadrons are deployed, they usually have small detachments located in various locations, ashore or afloat. Many of these sites can be very isolated and provide only a fuel truck and a runway, with no specialized support equipment to perform many scheduled maintenance functions. Certain phase and calendar inspections must be planned months in advance so the aircraft can be either: a) flown to a centralized maintenance hub where the squadron has the proper support equipment to perform these vital inspections, or b) inspectioned at the home base prior to deployment where facilities and proper support equipment are available to safely conduct maintenance (Marrs, 1995). This must be continually coordinated with the squadron operations department to ensure an adequate number of aircraft are available for operational commitments. All of these dynamic constraints place increased demand on effective maintenance scheduling in comparison to the commercial airline industry.

The aircraft maintenance managers and the scheduling methods and tools they use induce some degree of variability into the organization's scheduling problem. The following two sections describe preventive maintenance scheduling methods and tools used by Naval Aviation squadrons and commercial airlines, respectively.

B. NAVAL AVIATION SCHEDULING METHOD

Naval Aviation operates in an extremely complex and unforgiving environment, requiring numerous programs and constraints specifically designed to enforce the highest standards of quality and safety (Allen and McSwain, 1988, p. 47). An effective maintenance manager must be relatively familiar with all -- over three dozen (as shown in the Appendix) -- of these programs when making preventive maintenance scheduling decisions. In addition to this difficult task, a corrective maintenance plan must also be considered and integrated.

The nerve center for planning, staffing controlling and monitoring maintenance actions within the squadron resides in Maintenance Control. Typically, the senior enlisted maintenance manager, the Maintenance Master Chief (MMCPO), integrates a myriad of different information sources, mostly generated by his or her maintenance staff, to direct all corrective and preventive maintenance on squadron aircraft by establishing job priorities and assigning the maintenance workload to production work centers. The MMCPO's information base normally consists of the following items:

a. Present and following five month's calendars showing due dates for day-based periodic (calendar) inspections (see Figure 3);

b. "Time sheets" depicting time and cycles remaining for aircraft, engine and/or component inspections or replacements (i.e, phase and special inspections). This data is accumulated from NALCOMIS-generated reports, Figure 4 is an example of one of these reports. The collected data is usually displayed on a plexiglas "grease board", white eraseboard or blackboard in most squadrons;

c. Visual Identification Display System (VIDS) boards that organize computer-generated or manual Maintenance Action Forms (MAFs) into "In Work (IW)," "Awaiting Maintenance (AWM)" and "Awaiting Parts (AWP)" classes;

d. Other computer-generated readouts which reflect engine and/or structural fatigue life remaining for each aircraft;

e. Aircraft Discrepancy Books (ADBs) which reflect the configuration of the aircraft, the servicing status and the outstanding discrepancies on each aircraft (which theoretically match discrepancies on the VIDS board);

f. Julian Date calendar to calculate dates for periodic inspections;

g. Map depicting aircraft locations in the hangar and flight line (hangar bay and flight deck for carrier-based squadrons);

SPECIAL INSPECTION

July 23 - September 2, 1995

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
July 23 204/161	July 24 205/160	July 25 206/159 **321-14,28 330-14, 28,56**	July 26 207/158 **307-14,28, 56 327-14,28,56 343-14 344-14**	July 27 208/157 **326-14,28 347-14, 28,56**	July 28 209/156 **315-14 333-14 340-14**	July 29 210/155 **300-14,28, 56 341-14,28**
July 30 211/154	July 31 212/153 **314-14 317-14 331-14 335-14 361-14,28,56**	Aug 1 213/152	Aug 2 214/151 **325-14 332-14,28,84 345-14, 28,56**	Aug 3 215/150 **301-14,28, 56 322-14,84 357-14**	Aug 4 216/149 **305-14 362-14**	Aug 5 217/148 **306-14 342-14,28**
Aug 6 218/147	Aug 7 219/146 **310-14 324-14 354-14**	Aug 8 220/145 **314-14,28, 56 321-14 330-14**	Aug 9 221/144 **307-14 327-14 343-14,28,56 344-14, 28,56,448**	Aug 10 222/143 **316-14 326-14 347-14**	Aug 11 223/142 315-14,28,56, 224,448 333-14,28,56,84 340-14,28,56, 448	Aug 12 224/141 **300-14 341-14,28**
Aug 13 225/140	Aug 14 226/139 317-14,28 331-14,28,56,84 335-14,28,84, 364 361-14	Aug 15 227/138	Aug 16 228/137 **325-14,28, 56,84,448 332-14 345-14**	Aug 17 229/136 **301-14 322-14,28 357-14,28**	Aug 18 230/135 **305-14,28 362-14,28**	Aug 19 231/134 **306-14,28 342-14**
Aug 20 232/133	Aug 21 233/132 **310-14,28 324-14, 28,56 354-14, 28,56,84**	Aug 22 234/131 **314-14 321-14,28,56, 84 330-14,28,84**	Aug 23 235/130 **307-14,28 327-14,28 343-14 344-14**	Aug 24 236/129 **316-14,28 326-14, 28,56 347-14,28**	Aug 25 237/128 **315-14 333-14 340-14**	Aug 26 238/127
Aug 27 239/126	Aug 28 240/125	Aug 29 241/124	Aug 30 242/123 5-1	Aug 31 243/122	Sept 1 244/121	Sept 2 245/120

Figure 3. Example of a Squadron Long-term Inspection Schedule.

Hours Since Accept	Next Phase Due	30Hr Acft Due	50Hr Acft Due	100Hr Acft Due	200Hr Acft Due	400Hr Acft Due	600Hr Acft Due	Rmng Cats Traps	Total All Lndgs	P / S	Engine Serial Number	Time Since New	30Hr Eng Due	100Hr Eng Due	200Hr Eng Due	400Hr Eng Due
1209.7	190.3	18.1	32.6	71.6	190.3	390.3	590.3	173	2781	P	0360200	771.2	18.1	79.0	79.0	79.0
	C							32		S	0360053	1097.4	18.1	23.1	123.1	323.1
98.7	101.3	21.3	1.3	1.3	101.3	301.3	501.3	198	279	P	0360319	98.7	21.3	101.3	101.3	301.3
	A							100		S	0360321	98.7	21.3	101.3	101.3	301.3
48.7	151.3	11.3	1.3	51.3	151.3	351.3	551.3	200	142	P	0360293	48.7	11.3	51.3	151.3	351.3
	A							100		S	0360291	48.7	11.3	51.3	151.3	351.3
32.0	168.0	28.0	18.0	68.0	168.0	368.0	568.0	200	146	P	0360323	32.0	28.0	68.0	168.0	368.0
	A							100		S	0360317	32.0	28.0	68.0	168.0	368.0
2039.7	157.9	20.0	34.1	38.0	138.0	338.0		200	4695	P		0.0	30.0	100.0	200.0	400.0
	C							48		S		0.0	30.0	100.0	200.0	400.0
869.6	130.4	14.0	22.9	30.4	NA	330.4	330.4	116	1923	P	0360198	665.1	6.7	76.7	176.7	376.7
	A							16		S	0360055	849.7	15.0	25.0	125.0	325.0
2991.2	8.8	5.4	4.7	6.8	192.3	173.6	606.8	14	4394	P	0310175	2979.7	5.4	44.1	144.1	344.1
	C							41		S	0310419	4330.8	5.4	57.4	157.4	157.4
1816.4	-19.6	10.2	28.8	86.6	-13.4	-13.4	386.6	194	2997	P	0310660	2859.1	10.2	83.7	183.7	183.7
	A							18		S	0311998	2058.4	10.2	83.7	183.7	183.7
3277.3	126.4	6.7	52.0	102.0	134.1	334.1	334.1	54	4835	P	0311234	2284.9	6.7	61.1	52.5	52.5
	C							72		S		0.0	30.0	100.0	200.0	400.0
2348.8	51.2	28.7	22.6	99.1	0.1	200.1		130	2680	P	0311677	1980.5	21.2	37.1	37.1	37.1
	D							89		S	0310608	3469.9	21.9	56.1	177.5	377.5
2297.9	73.0	13.0	9.1	61.7	55.7	188.3	482.8	106	2980	P	0310427	4015.2	21.9	89.5	89.5	89.5
	D							7		S	0311187	2445.6	22.1	52.1	152.1	152.1
2278.6	121.4	5.9	32.4	21.6	121.4	121.4	-54.1	44	4344	P		0.0	29.7	88.1	188.1	188.1
	A							10		S		16.5	13.5	83.5	183.5	383.5
3218.0	43.5	5.4	36.6	36.6	136.6	336.6	136.6	147	4923	P		0.0	5.4	100.0	200.0	400.0
	D							NIS		S		0.0	30.0	100.0	200.0	400.0
1471.1	128.9	7.2	17.2	67.2	167.2	167.2	367.2	106	2416	P	0311129	2123.0	27.0	37.0	137.0	337.0
	D							62		S	0311292	2209.5	27.0	37.0	137.0	337.0
2174.8	25.2	10.0	31.5	25.2	25.2	25.2	27.2	109	4037	P	0310385	3796.0	10.9	30.1	30.1	230.1
	C							100		S	0310234	3030.1	12.9	92.9	92.9	292.9
3559.2	40.8	10.7	30.9	40.8	38.5	80.6	453.6	194	6870	P		0.0	30.0	100.0	200.0	400.0
	B							NIS		S		0.0	30.0	100.0	200.0	400.0
2765.7	34.3	6.2	48.8	48.4	164.5	7.5	495.7	129	5386	P	0311694	1582.0	7.1	70.4	170.4	170.4
	B							94		S	311898	2312.7	6.2	95.4	95.4	95.4
3331.8	68.2	15.4	43.9	68.2	51.4	80.1	101.6	41	6229	P	0310786	2631.8	17.7	37.7	37.7	237.7
	A							40		S	0311071	2391.0	17.8	77.6	77.6	277.6
3457.4	142.6	17.1	7.2	42.6	152.0	373.8	164.0	200	6755	P	0310654	3858.4	15.4	54.6	154.6	154.6
	B							100		S	0311911	2625.5	14.4	32.8	132.8	332.8
4167.5	132.5	28.0	53.1	32.5	132.5	352.4	550.7	131	7869	P	0310810	2769.5	22.0	78.5	178.5	178.5
	D							17		S	0310080	3207.4	22.0	55.8	55.8	55.8
2931.9	168.1	19.0	23.1	68.1	121.2	172.1	186.6	198	5953	P	0310074	3111.0	19.0	3.8	103.8	303.8
	A							94		S	0310795	2572.0	19.0	73.8	173.8	173.8

Figure 4. NALCOMIS Generated Report.

h. Daily department manpower assignment sheet depicting number of personnel and qualifications within each production work center;

i. Numerous publications delineating programmatic information; and

j. Daily flight schedule and weekly operational requirements schedule (at most up to six months).

Gathering all of this information together several times a day, the Maintenance Master Chief and the Maintenance/Material Control Officer (MMCO) develop weekly, monthly and semi-annual maintenance schedules by assimilating the above mentioned items. Using learned heuristic patterns, developed through fifteen or more years experience, they performs a rudimentary analysis of the maintenance situation at hand, while adjusting individual aircraft maintenance schedules to meet ever-changing resource constraints. Typically, this is performed under pressure with a limited response time, requiring numerous iterations to reach what appears to be a optimum plan. This decision-making process has a high probability of inducing mathematical mistakes and variability into the scheduling process (Marrs, 1995).

To aid the MMCPO and MMCO in managing inspection information, the Naval Aviation Maintenance Office (NAMO) and Navy Management Systems Support Office (NAVMASSO) have developed and fielded NALCOMIS, which serves as a automated database tool to provide the squadron maintenance managers timely

and accurate information (CNO, 1995, Vol IV, para. 7.3.4). Efforts continue to improve the flexibility of the atabase by providing more user-friendly information through the LMDSS management information system. Nevertheless, NALCOMIS and LMDSS only provide the MMCPO and MMCO information -- which is only as good as the information that is entered into the system. Neither system provides substantial decision making assistance; the MMCPO still uses this information in printed format and graphs out his schedules using pencil, paper and greaseboards. Typically, many manhours and days are spent drawing, evaluating and redrawing plans in a cyclic nature.

Another administrative tool that the MMCPO and MMCO can use either advantageously -- or disadvantageously -- is the deviation rule for preventive maintenance actions. Those actions based on operating hours, cycles or events -- phase inspections, special inspections and scheduled component removals -- are allowed a plus or minus ten percent limit deviation to facilitate easier maintenance scheduling. This does not apply, however, to structural and life-cycle fatigue (LCF) limited items which have reached their limit. A plus or minus three-day limit deviation rule can be applied to calendar inspections. Furthermore, any inspection can be performed earlier than the ten percent or three-day window if discretion allows. The limit deviation window can only be exceeded during combat situations; this requires exceptionally high authority outside the squadron for approval (CNO, 1995, Vol. I, para.12.1.6.3).

The Type and Operational Wings, the squadron's next higher authority, place other operational and maintenance constraints on

the squadrons under their command. All of these must be considered during the decision process. Even though communication is crucial between the wings and both the squadrons' operations and maintenance departments, the wings also rely on the same paper and greaseboard tools. In the case of maintenance, the communications between the wing and its squadrons normally involve submission of individual morning status reports which are typed or handwritten the night before. Figure 5 represents one of these daily reports.

Since this data is not real time, the wing receives phone updates the following morning. In turn, the wing must make quick and accurate decisions affecting ongoing operations and maintenance without having the current squadron operational and maintenance schedule readily available.

The daily flight schedule and weekly operational requirements schedule, generated and promulgated by the squadron's operations department, tends to provide the focus for the entire scheduling process. Squadron aircrew aggressively plan to fly the squadron aircraft as much as possible, maximizing aircraft utilization for operational and training requirements, while sacrificing adequate preventive maintenance time. The intense pressure on the MMCPO to provide multiple aircraft for daily operational and training requirements can potentially lead to less than optimum utilization of inspection deviation windows, inducing large variabilities into the preventive maintenance schedule. The demand for aircraft in the upcoming days might force the MMCPO to perform the inspection prior to the minus ten percent/three-day window. Not only does

DAILY AIRCRAFT READINESS REPORTING

FA-18C		14 SEP 95	AMEL
TYPE ACFT	ACTIVITY	DATE	PREPARED BY

ASSIGNED	11	TOTAL NR OF ACFT ASSIGNED.
MCAPP	0	NR OF ACFT IN MCAPP (D10) OR IN STATUS CODES E_F_B_ OR C_.
OUT RRS	0	NR OF ACFT OUT READINESS REPORTING STATUS CODES H_G3_G4_.
RRS	11	NR OF ACFT IN READY REPORTABLE STATUS.
MC	5	NR OF ACFT NOT HAVING AN EOC CODE OF Z_ ASSIGNED.
FMC	5	NR OF ACFT NOT HAVING EOC CODES OF C_ - Z_ ASSIGNED.
NMCS	2	NR OF ACFT DOWN FOR SUPPLY WITH EOC CODE OF Z_ ASSIGNED.
NMCM	4	NR OF ACFT DOWN FOR MAINT WITH EOC CODE OF Z_ ASSIGNED.
SOR SKED	0	NOTE: A. ALL SORTIE AND FLIGHT HOUR FIGURES REPORTED MUST BE SINCE THE PREVIOUS REPORT.
SOR FLN	0	B. NMCM + NMCS + MC MUST EQUAL RRS. OUT RRS + MCAPP + RRS MUST = NR OF ACFT ASSIGNED.
FMC SOR	0	
FLT HRS	0	C. DO NOT COUNT MCAPP ACFT IN OUT RRS COLUMN.

NMCM ACFT

BUNO	DATE DOWN	DISCREPANCY	EST UP DATE	EOC
164	11 SEP 95	400 HR NDI	22 SEP 95	
164	11 SEP 95	400 HR NDI	19 SEP 95	
164	28 JUL 95	TANK PRESS LC	15 SEP 95	Z
164	12 SEP 95	GUN	14 SEP 95	

NMCS ACFT

BUNO	MAJOR PARTS ON ORDER	DOC NR	MILSTRIP STAT
164	HDU	5221 GE17	233 WQ
164	HDU	5144 GE42	080 WQ

LIST ALL ACFT NOT FLOWN IN OVER 15 DAYS AND ACFT REPORTED AS SPINTAC ALERT, SPINTAC, MCAPP, OR OUT OF RRS.

SIDE NR	BUNO	LAST FLY DATE	STATUS CODE	REASON NOT FLOWN	SPINTAC ALERT/ SPINTAC/MCAPP/ OUT RRS MSG DTG
02	164	15 MAR 95	A10	NMCS	031210Z AUG 95
03	164	24 JUL 95	A10	NMCS	221212Z AUG 95
07	164	28 JUL 95	A10	NMCM	271210Z AUG 95
12	164	29 JUN 95	A10	NMCM	281210Z AUG 95

Figure 5. Example of a Squadron's Daily Report.

this negate the opportunity to fly potentially operational aircraft for a few days more, but also causes inefficient use of manpower, materials and facilities which will have to be used that much sooner when the aircraft becomes due for the same inspection again.

As the MMCPO and MMCO have to contend with conflicting priorities between operations and maintenance requirements, it is readily apparent that most of their scheduling decisions induce undue variability into the maintenance process, producing a less than optimal plan. Thus, the MMCPO, probably not as productive as he or she can be, in turn possibly reduces the productivity of the entire Maintenance Department by increasing inefficiencies in maintenance scheduling, thus increasing aircraft turnaround time.

C. COMMERCIAL AIRLINES SCHEDULING METHOD

Commercial airlines operate in a more predictable and routine environment. Following a similarly programmatic structure to Naval Aviation, the effective airline maintenance manager makes maintenance scheduling decisions over the course of months and years, rather than days. This is primarily due to the emphasis on depot-level periodic inspections projected over long, well-defined operations.

At each airport serviced by a particular commercial airline, a small pool of organizational-level maintenance personnel perform minor servicing, turnaround inspections, aircraft movement and limited corrective maintenance. Major corrective maintenance for non-flyable discrepancies is performed by field teams dispatched

from the airline's central maintenance facilities. Thus, the great majority of preventive maintenance performed by major commercial airlines is performed at these large, sprawling maintenance hubs -- essentially depot-level facilities. For instance, American Airlines performs over thirty different types of periodic maintenance inspections on its approximately 600 aircraft, consisting of 10 different types, at its hubs in Fort Worth, Texas and Tulsa, Oklahoma (Gray, 1992, p. 21).

Up until 1991, American Airlines used manual scheduling methods quite similar to those presently used in Naval Aviation squadrons. In the late 1980's, aircraft maintenance and utilization data were integrated into an automated spreadsheet; along with facility production line charts, maintenance planning still remained a tedious and time-consuming task for even the most experienced maintenance managers. It normally took them two weeks to generate a two-year preventive maintenance plan (Tobler, 1992, p. 1), which was generally inaccurate and obsolete by the time it was distributed to engineers and maintenance technicians (Gray, 1992, p. 25).

By late 1991, however, American Airlines developed and implemented an automated decision support system called DockPlan to assist, not replace, maintenance managers in developing preventive maintenance schedules. Since the airliners' inspections and forced component removals are based on number of cycles and operating or flight hours, the routine nature of airline flights easily facilitates estimating daily aircraft utilization for the entire fleet. By

continually matching the daily aircraft utilization against allowable hour or cycle limits for each aircraft, the DockPlan program can easily compute each aircraft's "drop dead" date.

Another large commercial airline, United Airlines, has also followed suit in recent years. Up until several years ago, United's Maintenance Operations Division also used iterative manual methods for scheduling preventative maintenance actions on their 560-aircraft fleet. Management efforts in developing several intergrated maintenance information systems has led to improved scheduling practices while, increasing aircraft utilization (Hunter, 1995).

United Airlines is also developing and implementing a automated DSS called DockVisit, which should be fielded by early 1996. This system operates similarly to American's DockPlan, and is intended to serve as a functional management tool to further optimize the use of "constrained resources" (McLain, 1995).

To adequately measure the effectiveness of the maintenance schedule, the number of hours (or cycles) expended between performance of each type of inspection compared to the allowable limit is determined, producing a metric known as the Maintenance Check Yield, which is expressed as a percentage of allowable yield. Another metric required is the Maintenance Facility Capacity, which reflects the limitations associated with the available amount of manpower, hangar space and support equipment in regards to the aircraft fleet type and size.

DockPlan attempts to optimize the Maintenance Check Yields while minimizing Maintenance Facility Capacity. This is performed against various operational constraints, such as:

a. Changing fleet size and composition (deliveries and transfers);
b. Seasonal demand changes in utilization;
c. Similar inspections must be performed on similar aircraft fleet types in the same maintenance facility;
d. Facility utilization must be relatively constant; and
e. Maintenance inspections must be performed within upper and lower allowable limits (not performed too early).

The DockPlan system gathers information from an integrated database containing maintenance and flight profiles, rendering paper readouts and charts obsolete. It operates on a standard Macintosh personal computer, supported by Microsoft Word and Excel software programs. Consisting of several different modules, it enables maintenance managers to organize and assimilate maintenance planning data; quickly construct an effective maintenance schedule; and produce various reports to assess the preventive maintenance schedule. DockPlan's "interactive optimization" methodology integrates the maintenance manager's experience with the "computational power of a simple, computerized scheduling heuristic algorithm" (Gray, 1992, p. 26). In view of the complex constraints, the maintenance manager attempts to reach a optimal schedule by

iteratively running numerous problems and evaluating each one on its own merit -- that is, getting the Maintenance Check Yield as close to 100 percent as possible. To develop a maintenance schedule for a five year plan, this interactive process takes all but a few minutes of the maintenance manager's time. According to Gray (1992, p. 26), "[t]his elevates the scheduler from the level of a number crunching 'technician' to a 'maintenance planner and analyst.'"

D. SUMMARY AND CONCLUSION

As outlined in the two preceding sections, both Naval Aviation and commercial airline preventive maintenance scheduling methods aspire to attain an optimum level. The maintenance managers of each type of organization, working in small staffs, use iterative techniques in attempts to strike a balance between operational and maintenance requirements while dealing with numerous regulatory constraints and other externalities.

However, notable contrasts exist between the methodologies used by both organizations. Because of the demanding and highly dynamic operating environment, Naval Aviation squadrons focus on a relatively short-term scheduling horizon which is adjusted almost daily. Commercial airlines, on the other hand, use a five year scheduling horizon, updated monthly, because of their more predictable flight operations. Naval Aviation squadrons' maintenance skills are strictly organization-level, while the commercial airlines' maintenance skills are more characterisitic of depot-level maintenance.

The scheduling system used by the squadrons centers around the decisions made by the MMCPO and MMCO, who integrate paper-based information sources to build schedules by manually "crunching" numbers and adjusting parameters over and over, usually taking 30 to 60 minutes to complete the process, and obtaining outcomes which are relatively accurate. Utilizing an integrated software approach, a single production scheduling coordinator in a commercial airline maintenance operation can perform scheduling iterations in three to eight minutes, resulting in a much more mathematically accurate schedule.

Due to the limited tools used within the Naval Aviation's scheduling process, it is mostly reactive and is subject to much variability. With the faster assimilation of information, the commercial industry has less variability in their preventive maintenance schedules and promotes a proactive approach. Both of these organizations' overriding goals are the same -- flying aircraft on time, safely and in the most efficient manner. Nevertheless, it is obvious that the methods used to achieve these goals are quite different in terms of technology. The next two chapters will examine how these differences in technology directly impact the costs and benefits of the two scheduling methods.

III. COST BENEFIT COMPARISON

A. INTRODUCTION

As highlighted in Chapter I, aircraft operations exist in a highly dynamic environment, with degrees of variability in aircraft utilization, system configuration, operational requirements and resources (i.e, facilities, manpower, support equipment). One tactic to reduce the variability of these factors is to improve preventive maintenance procedures (Heizer and Render, 1993, p. 801). This tactic can be taken one step further by improving the scheduling of preventive maintenance actions.

In today's volatile budgetary and economic climate, both military and airline operations must strive to perform maintenance procedures more effectively and for less costs. For any organization, equipment maintenance is vital to sustaining the capability of systems while controlling costs. Military aviation commands and airlines hold fast to the belief that aircraft maintenance, if not performed properly and efficiently, can have detrimental and possibly catastrophic effects on operations and profits (Heizer and Render, 1993, p.800). This chapter compares the costs and benefits, with a strong emphasis on the opportunity costs, of the present scheduling method used throughout Naval Aviation with a proposed automated DSS, similar to commercial airline methods, integrated into present-day Naval Aviation scheduling architecture.

B. METHODOLOGY

The authors strived to reduce the amount of subjectivity associated with these cost and benefit factors by attempting to interview numerous maintenance managers across a wide spectrum of Naval Aviation. Data was collected from squadrons located at NAS Whidbey Island, Washington and NAS Lemoore, California. Personal interviews were held with personnel who were involved in scheduling maintenance, including data collectors, supervisors, managers and type wing personnel. Some wing and squadron personnel at both locations had previously received a brief and demonstration by a commercial company on how a current commercially available DSS system is working with a large international airline. A portion of interviews review the information that the Navy personnel obtained from the commercial brief and how they perceived the Navy could utilize a similar system. The interviews also included how their organizations currently schedule maintenance and the problems they encounter. The scheduling and communication tools, which included grease boards, hand-written reports and spreadsheets, were also studied at each command.

C. COST COMPARISON

1. Personnel

As explained in Chapter II, the scheduling of preventive maintenance actions at the Naval Aviation organizational level -- supporting ten aircraft on average -- requires that the MMCPO and MMCO spend several hours a day in any squadron (up to six hours

daily in one case) to ensure that all programmatic constraints and operational commitments are satisfied (Marrs, Robirds, Simon, 1995). This time period is generally proportional to the number of iterations which are performed in attempting to find the "best fit" of maintenance requirements given operational goals. Tasks performed during these iterations include inputting maintenance data, calculating output data, analyzing the outputs, developing a draft schedule, and possibly reconfiguring output data given other alternatives.

On the other hand, an automated decision support system can perform the same iterative tasks in a fraction of the time. When United Airlines switched from a manual to an automated pesonnel scheduling system the time required to develop the schedule was drastically reduced. The supervisor previously spent eight hours a day writing the schedule. Once this tedious task was automated, the time was reduced to two hours, giving the supervisor more time to manage (Reams, 1995). (See Figures 6 and 7.)

Twelve tests were conducted using a representative program, SABRE Corporation's DockPlan, for a ten-aircraft scheduled maintenance plan integrating operational requirements. Schedule generation time averaged just less than two minutes for a six-month schedule utilizing the software on a 60MHZ Power Macintosh computer. If input data can be directly integrated from the NALCOMIS database into the DockPlan system, the entire iterative maintenance scheduling process, taking into account several

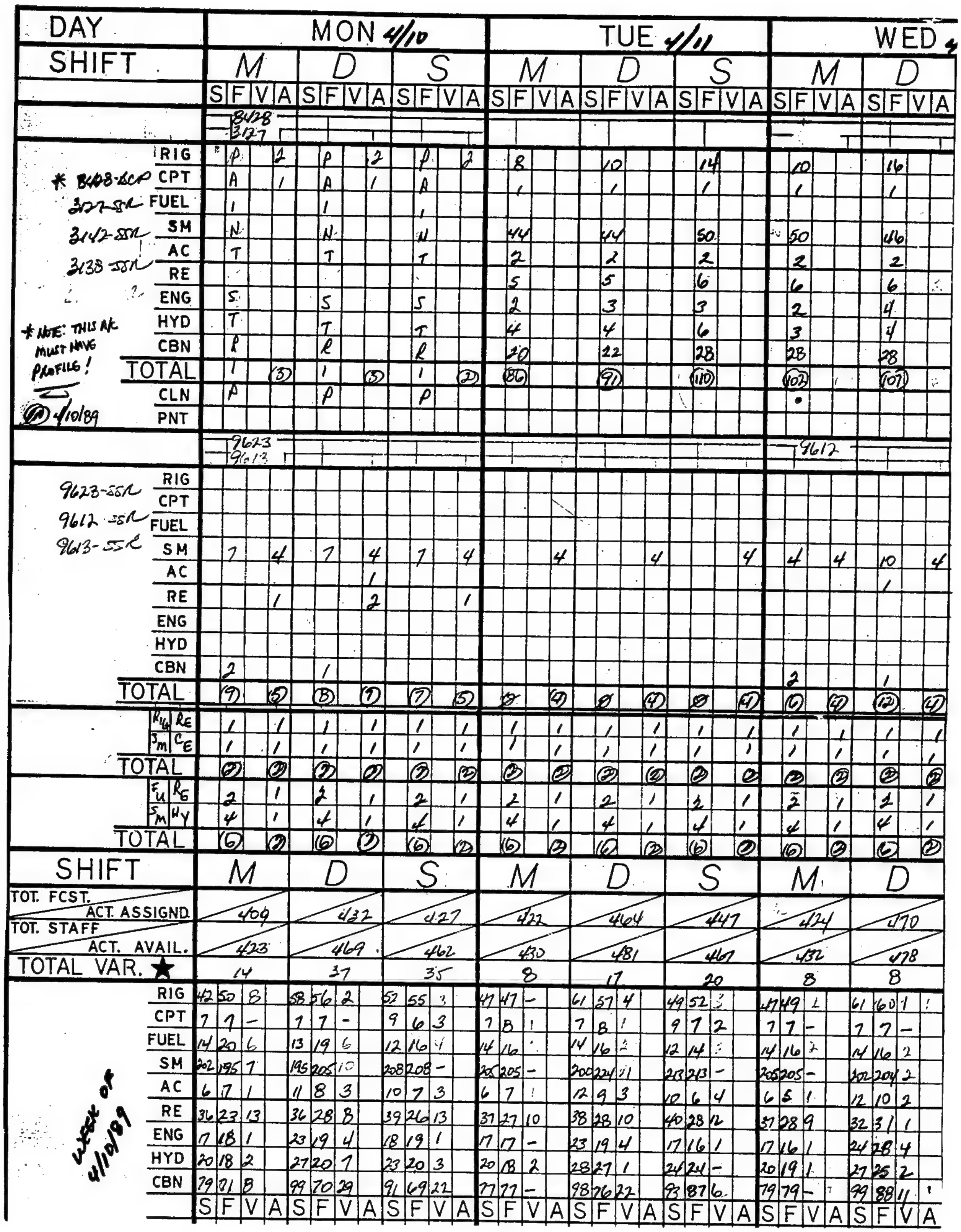

Figure 6. United Airlines Manual Scheduling Plan.

Production Planning - Available versus Profiled - as of 14:51:09 on 10/24/95

Manpower Balance for 10/23/95	Midnights			Days			Swings		
	Avl	Pro	Var	Avl	Pro	Var	Avl	Pro	Var
Gen	61	68	-7	77	76	1	67	69	-2
Ckp	7	8	-1	6	7	-1	8	7	1
Fuel	4	6	-2	16	18	-2	12	14	-2
S/M	82	76	6	89	81	8	81	79	2
R/E	34	35	-1	37	37	0	37	36	1
Cab	60	57	3	59	63	-4	62	65	-3
	248	250*	-2	284	282*	2	267	270*	-3
Cln		110	110		0	0		0	0
Pnt		0	0		0	0		0	0
* Includes Fuel Crew Numbers + Fuel Req'd									

Manpower Balance for 10/24/95	Midnights			Days			Swings		
	Avl	Pro	Var	Avl	Pro	Var	Avl	Pro	Var
Gen	64	64	0	76	67	9	75	64	11
Ckp	8	8	0	6	7	-1	7	7	0
Fuel	4	6	-2	14	16	-2	14	16	-2
S/M	87	82	5	92	82	10	86	82	4
R/E	37	38	-1	38	40	-2	39	38	1
Cab	62	60	2	65	63	2	62	63	-1
	262	258*	4	291	275*	16	283	270*	13
Cln		6	-6		0	0		0	0
Pnt		0	0		0	0		0	0
* Includes Fuel Crew Numbers + Fuel Req'd									

Manpower Balance for 10/25/95	Midnights			Days			Swings		
	Avl	Pro	Var	Avl	Pro	Var	Avl	Pro	Var
Gen	64	67	-3	78	68	10	76	62	14
Ckp	8	6	2	6	7	-1	7	6	1
Fuel	4	6	-2	16	18	-2	14	16	-2
S/M	86	72	14	92	72	20	89	66	23
R/E	37	36	1	39	37	2	39	35	4
Cab	61	60	1	63	57	6	63	53	10
	260	247*	13	294	259*	35	288	238*	50
Cln		19	-19		0	0		0	0
Pnt		4	-4		0	0		0	0
* Includes Fuel Crew Numbers + Fuel Req'd									

Manpower Balance for 10/26/95	Midnights			Days			Swings		
	Avl	Pro	Var	Avl	Pro	Var	Avl	Pro	Var
Gen	65	74	-9	80	81	-1	71	75	-4
Ckp	8	7	1	6	7	-1	6	7	-1
Fuel	4	6	-2	16	18	-2	13	15	-2
S/M	84	75	9	92	75	17	86	72	14
R/E	36	47	-11	39	48	-9	36	45	-9
Cab	60	72	-12	63	75	-12	62	73	-11
	257	281*	-24	296	304*	-8	274	287*	-13
Cln		76	-76		0	0		0	0
Pnt		0	0		0	0		0	0
* Includes Fuel Crew Numbers + Fuel Req'd									

Manpower Balance for 10/27/95	Midnights			Days			Swings		
	Avl	Pro	Var	Avl	Pro	Var	Avl	Pro	Var
Gen	60	75	-15	76	75	1	73	67	6
Ckp	8	8	0	5	8	-3	6	9	-3
Fuel	4	6	-2	16	18	-2	14	16	-2
S/M	84	78	6	90	75	15	86	73	13
R/E	39	46	-7	39	48	-9	36	45	-9
Cab	62	76	-14	64	77	-13	62	76	-14
	257	289*	-32	290	301*	-11	277	286*	-9
Cln		50	-50		0	0		0	0
Pnt		0	0		0	0		0	0
* Includes Fuel Crew Numbers + Fuel Req'd									

Figure 7. United Airlines Automated Scheduling Plan.

iterations by the MMCO and MMCPO, could be reduced to as little as 45 to 60 minutes a day.

Each squadron studied used the same basic tools to set up their maintenance plan, grease boards and simple spreadsheets. However, their management styles differed in terms of priorities and scheduling horizons. This was due to different environmental constraints, aircraft types, and personalities involved. The representative P-3C squadron managers looked out six to nine months when they set up their plan. They concentrated on aircraft transfers and deployment preparations. The missions they were involved with did not require a lot of aircraft reconfiguration. Managers in the representative FA-18C squadron focused on a three

to four week window. This was due to the fact they were constantly preparing for short detachments while at home base. The detachment requirements were constantly changing. Aircraft configuration was more complex with the FA-18C due to the various types of missions involved. Planning around the bombing range schedule was also a major constraint. It was normal to have less than a week's notice for a range requirement. The FA-18C squadron managers had to be more flexible in their scheduling due to these additional variables.

By studying these two different types of squadrons, an average of the manhours required to prepare and maintain the maintenance schedule was derived. The rate and days per year in Tables 1 and 2 were based on the 1995 Composite Standard Military Rates (DON, 1995).

An average squadron using a software-based automated DSS currently being utilized by commercial airlines would require the following manhours listed in Table 2 (Gantt, 1995). The annual opportunity cost savings per squadron by dollars and manhours, based on these estimates, are listed in Table 3.

P-3 Squadron			F/A-18 Squadron		
RANK	HRS	RATE(per hr)	RANK	HRS	RATE(per hr)
W-3	1	$33.09	O-2	1	$27.56
E-9	6	32.65	E-9	2	32.65
E-7	1	23.91	E-8	2	23.91
E-4	3	14.09	E-4	1	14.09
Daily Total:	$295.17	11 hrs	$154.77	6 hrs	
Annual Total:	$76,744.20	2860 hrs	$40,240.20	1560 hr	
Squadron Annual Average:	$58,492.20	2210 hrs			
(based on 260 days per year)					

Table 1. Manhours and Rates

<u>Source:</u> Marrs (1995) and Simon (1995)

	RANK	HRS	RATE(per hr)	
	O-2	.5	$27.56	
	E-9	1.5	32.65	
	E-7	.5	23.91	
Daily Total: $74.69	3.0 hrs		Yearly Total: $19,419.40	780 hrs

Table 2. Manhour Estimates with DSS

Navy (manual)	$58,492.20	2210 hrs
Commercial (automated)	$19,419.40	780 hrs
Opportunity Cost Savings	$39,072.80	1430 hrs

Table 3. Annual Opportunity Savings of Personnel Costs with DSS

2. Equipment

The Navy presently spends no additional funds for an organizational-level maintenance scheduling DSS. Estimated costs for installing a DSS into a P-3C squadron, for example, based on economies of scale, are listed in Table 4 (Gray, 1995).

1 squadron	$200,000	each
2-10 squadrons	100,000	"
11-20 "	75,000	"
21-35 "	50,000	"

Table 4. DSS Installation Estimates

These estimates would include software license fees, installation, training for two personnel in each squadron and user manuals. They would also include five years of technical support.

The additional hardware required per squadron would build off the current NALCOMIS infrastructure of personal computers (PC). This system is being upgraded to 100Mhz Pentiums for 1996, at a

cost of $2,000 per unit (Ezzard, 1995). One additional PC would be required for the maintenance department. This is necessary so the maintenance manager could have immediate access to the system and be able to make changes to the schedule in a easy and timely manner.

D. BENEFITS

There are numerous benefits associated with both methodologies in the areas of process time, complexity, training, flexibility, long-term strategic planning, adaptability, communications, and aircraft utilization and readiness.

1. Process Time

One of the obvious benefits of automating a complex task is reducing the process time that it requires to complete the task. In the Naval Aviation maintenance scheduling process, much of the maintenance data has been integrated into a single automated database, NALCOMIS, which has reduced the time required to access and refer to specific historical maintenance events needed for planning future courses of action. Nevertheless, this reduction in process time has been significantly offset by the increased amount of maintenance data which needs to be integrated into the decision making process. This increase in maintenance data is due primarily to the complexity of aircraft systems and the ancillary methods used to track pertinent cycles or indices. Thus, present-day maintenance planners must still set aside a considerable part of their working day to generate a plan and, if time allows, to examine alternative plans.

As pointed out in C. 1 in this chapter, the time savings through the use of an automated DSS for maintenance scheduling is readily apparent.

2. Complexity

The scheduling system presently used in Naval Aviation squadrons is relatively simple in terms of the tools and technologies used in the planning process; however, even with the addition of automated databases such as NALCOMIS and LMDSS, it remains a very complex system when viewed in terms of integration. All of the squadrons interviewed used similar methods in tracking scheduled maintenance requirements. This is due to the present capability of NALCOMIS to only display (in tabular format) the next inspection due for each type of inspection. This information, in turn, is transcribed to a grease board and Excel spreadsheet, a WordPerfect matrix resembling a calendar, or a Calendar Creator-type program that has the ability to reflect recurring events in a calendar format. Only the grease board format shows the interactions involved in performing maintenance on an entire fleet. Schedules from the Operations Department and the Wing Maintenance Department, formatted in similar but non-integrated databases, must also be integrated into the maintenance schedule to reflect operational and incidental aircraft requirements.

Containing a visual graphic capability to produce Gantt-type charts for an entire fleet, a commercially-available automated DSS, such as DockPlan, effectively eliminates the need for additional calendars and databases to be constructed in major airline

maintenance departments. Figure 8 is an example of the DockPlan modified for the presentation that was given at NAS Lemoore and NAS Whidbey Island. This reduced workload for the maintenance administrative staff (to build and maintain the ancillary databases) and the maintenance managers (to review and integrate the information) improved productivity of the managers and supporting staff, affording them more time to focus on problems where more effort is required.

3. Training

The inherent complexity of the present Naval Aviation maintenance scheduling methodology induces similar problems in the viewpoint of training personnel to effectively use the scheduling systems that are unique to each squadron. The maintenance administrative staff must be adept at inputting and configuring maintenance data within several databases, including NALCOMIS and Engine Component Automated Maintenance System (ECAMS), in order to provide formatted reports and calendars to the maintenance managers. Since these reports and databases, excluding NALCOMIS and ECAMS, vary for each squadron, it takes the average Aviation Maintenance Administrationman (AZ rating) normally three to four months to learn and become proficient with the maintenance scheduling system.

Moreover, the maintenance managers in each squadron must become familiar with new databases when they report to a new squadron. Or, to make matters worse, they might introduce a new database or format with which they are personally familiar,

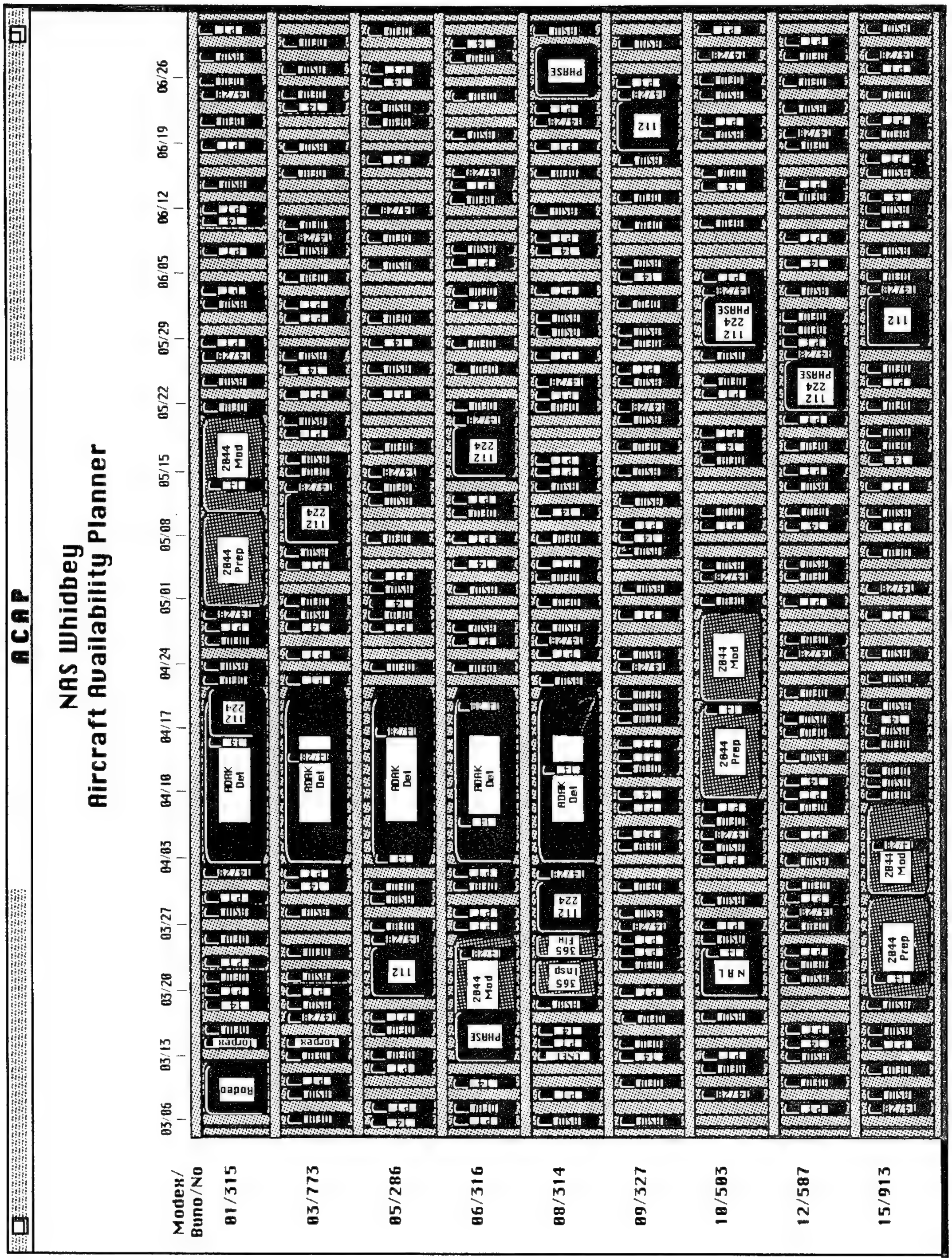

Figure 8. Modified DockPlan Chart.

requiring the maintenance administrative staff and other squadron maintenance managers to start the process over again and learn a new system or format. This, in turn, reduces the productivity and effectiveness of the entire maintenance department, taking away management and production time for essential training.

With a DSS integrated into the airlines maintenance data system, the need for training on multiple databases is greatly reduced, as well as the various requirements for numerous formatted reports and calendars. This is because training on the use of a commercial DSS and how to configure its reports is already an integral part of the maintenance data system training process within the airlines.

4. Flexibility

The present maintenance scheduling system used in Naval Aviation squadrons possesses a large degree of flexibility. For the comparison purposes of this thesis, flexibility is defined as the ability to integrate dynamic operational and maintenance changes into the maintenance schedule. Because the present scheduling system depends on numerous databases with different types of information, the handwritten maintenance schedules (on paper or grease board) allow for quick inclusion of changes. However, the present methodology takes hours to reflect how these changes affect the long-term maintenance schedule. The FA-18C squadron maintenance departments which were interviewed valued this flexibility in the weekly schedule, but were not greatly concerned about how these schedule changes would affect the maintenance schedule after the upcoming operational or training commitment. The P-3C squadron,

on the other hand, tended to look more at a longer period of time on a daily basis and put a larger emphasis on observing downstream effects of schedule changes.

Given an integrated DSS within the NALCOMIS system, the amount of flexibility would be similar as long as the information migrated directly from the LMDSS database into the DSS. The DockPlan configuration that was evaluated during the course of this thesis, which was not integrated with the LMDSS database, required a large amount of data manipulation greatly reducing the flexibility of the prototype system.

Additionally, the DockPlan method did not afford the same flexibility as the present Naval Aviation maintenance scheduling method in respect to accommodating specific operational requirements. The MMCO and the MMCPO, given their experience in dealing with different mission requirements (i.e.., bombing, anti-submarine warfare, missile firings, and low-level training) for their particular squadron, are able to assimilate the operational requirements and schedule particularly configured aircraft, possibly numerous times a day, for these specific missions. The DockPlan system the authors examined allowed for manual inputting of aircraft operational commitments, but not to the extent that the Gantt-type chart could reflect specific-type missions, particularly multiple missions, on a day-to-day basis.

5. Adaptability

Adaptability is a crucial factor to any scheduling system in terms of how deployable the scheduling system is and how well it can

integrate with existing and proposed maintenance information systems and different type/model/series of aircraft. The maintenance scheduling system presently used at the Naval Aviation organizational level, because of its relative simplicity, can be deployed anywhere, ashore or afloat, for extended periods of time as long as there is a resident NALCOMIS system available. The scheduling system can even operate for periods of time without the availability of NALCOMIS.

NALCOMIS is configured to handle maintenance data for all naval aircraft, regardless of type/model/series. The major exception to this is the engine and structural fatigue life data, which is not based on flight hours, cycles or calendar days (e.g. FA-18C and F-14D). An automated DSS, such as DockPlan, used by commercial airlines, is structured to provide graphical projection based on flight hours and cycles. Since airlines do not have fatigue life constraints, present systems do not integrate these elements. This DSS system can also operate for periods of time without integrated data systems through manually inputting maintenance data into the software.

6. Communications

One of the greatest problems experienced through the authors' experience and validated during research is the complexity of keeping all interested parties (operations, wing, training, maintenance work centers) informed when changes to the maintenance schedule occur. This problem tends to be two-fold; first, the various calendars, readouts and charts are not integrated in a real-time fashion, so the redefined maintenance schedule must be

promulgated through different channels and then updated on all of these calendars, readouts and charts. Since most of this is performed manually, the change may be out of date before it is received by the user. Secondly, the format of this information is not at all uniform. This can result in misunderstandings by the interested parties outside the Maintenance Control environment.

Given the assumption that the automated DSS would be integrated into the NALCOMIS and ECAMS databases, and reflect real-time data and requirements, all interested parties would receive the same formatted report that the MMCO and MMCPO promulgates. A Gantt-type chart format, similar to DockPlan's output, would provide the best visual aid to look at the entire fleet over a given period of time. This would minimize miscommunications between the Maintenance Department, Operations Department, the wing and other interested parties.

7. Long-term/Strategic Planning

As alluded to in the paragraph on flexibility, some squadron maintenance departments are so constrained by the dynamic environment with which they operate that they have little opportunity or motivation to plan their maintenance schedule past the next operational commitment. Without examining the future effects of their decisions in adjusting the maintenance schedule, they probably operate on a less than optimal level in terms of resource allocation and/or aircraft readiness. One squadron which was observed placed much emphasis on the future (six to seven months in advance) effects of their maintenance management decisions in

terms of optimizing projected available resources and aircraft availability. However, this took a tremendous amount of time for the MMCPO and MMCO to perform, detracting from their ability to focus on more immediate goals and objectives.

An automated DSS, containing an optimization algorithm and operational and programmatic constraints within the software, would enable any squadron to rapidly input, assimilate and analyze any maintenance schedule. The ability of the optimization algorithm to push for the "best fit" in balancing operational and maintenance constraints in order to maximize aircraft availability enables the MMCPO and MMCO to place more emphasis on examining the long-term effects of changes to the maintenance schedule.

8. Aircraft Utilization and Readiness

In view of all the aforementioned factors, aircraft utilization and readiness (mission capability) are viewed as the "bottom lines" throughout Naval Aviation. A representative FA-18C squadron maintained an average aircraft utilization rate of 23.7 hours/month over a recent six-month period (VFA-25, 1995, p. 2). In a P-3C squadron, aircraft utilization averaged 52.7 hours/month over the same six-month period (Rodriguez, 1995). By using DockPlan, American Airlines was able to increase aircraft utilization by 18.75% for their widebody fleet over a period of four years (Gantt, 1995). By comparison, it is possible for the representative FA-18C squadron to improve their utilization using a similar DSS by the same percentage, up to 28.1 hours/month over a 4-year period. Similarly,

the P-3C squadron could theoretically improve its aircraft utilization rate to 62.6 hours/month.

Improved aircraft utilization also translates to improved aircraft readiness. The ability of present-day Naval Aviation maintenance scheduling methods to account for future resource allocations is limited by the ability to foresee effects of current maintenance schedule changes. Thus, improved visibility of these effects and the opportunity to take appropriate action potentially offers great potential for improved aircraft readiness.

IV. COST BENEFIT ANALYSIS

A. INTRODUCTION

Economic factors are a major influence on maintenance programs. As aircraft become more complex, they also become more expensive to maintain unless timely and specific steps are taken during the design process to improve reliability and maintainability. Any new program that can increase readiness while reducing cost should be considered.

The commercial airlines' maintenance software programs used to determine scheduled maintenance requirements for the large widebody fleets have greatly increased economic efficiency. American Airlines increased average long-term aircraft utilization after installation of the Dock Plan from 80% to 95%. Moreover, the major overhaul checks performed over the lifetime of an aircraft are expected to be reduced by one or two checks at about one million dollars per check (Gantt, 1995). Additionally, "within three months of installing the computerized maintenance planning system, American Airlines estimates it saved $8-13 million" (Tobler, 1992). This was primarily attributed to the increased efficiency in scheduling hangar space, one of their critical resources, allowing the airline to complete interior maintenance which previously had to be contracted out. A more efficient, foresighted method of scheduling maintenance greatly assisted American Airlines to better utilize their resources.

When considering the cost and benefits of a DSS program, not only must the current costs be considered but also the complete life cycle costs (LCC) of the weapon system it is intended to support. This thesis deals primarily with cost savings at the organizational-level of maintenance, but when the LCC is considered, the authors foresee many cost saving benefits that can occur at the depot-level. These benefits go beyond the scope of this thesis.

B. COST BENEFITS

The opportunity cost benefits are very apparent when analyzing personnel. The average reduction in manhours would be approximately 1,430 annually per squadron if an automated DSS were implemented. This is 65% less time required for scheduling and preparing the maintenance plan. The hours previously spent on scheduling could be better utilized on managing the maintenance department. In the case of American Airlines, the installation of the DockPlan "essentially turned the analyst, who in the past was a number cruncher, into a real analyst. It gave analysts time to say: what can I do to make better use of what we have" (Tobler, 1992, p.1). Similar results are anticipated in United Airlines upon implementation of their DockVisit DSS (Hunter, 1995). The managers could place more emphasis on better resource planning, personnel safety, training, and morale.

In some squadrons, maintenance staff personnel could be realigned because an automated DSS would greatly reduce the need to produce handwritten reports. This would reduce the scheduling

workload on the lower ranking enlisted positions. In addition to the daily and weekly maintenance scheduling plans produced, many reports required in the monthly maintenance plan could also be retreived directly from the computer program. If, for example, the preparation for handwritten reports was reduced or eliminated, decreasing the need for an E-4 by 50%, an annual opportunity cost savings would be:

260 days * 4 hrs (based on an 8 hr day) * $14.09 = $14,653.60.

This E-4 could be placed on other tasks which are usually short handed, such as organizing training, supervising administrative personnel, or handling the Phase Maintenance administrative workload.

The personnel opportunity cost savings of over $39,000, calculated in Chapter III alone, would equal the estimated equipment costs within about 18 months based on the assumption that the best economy of scale would be utilized.

For these equipment cost estimates to be accurate, it is crucial that a DSS program purchased for the Navy be adaptable to current and projected database systems. It must be able to integrate smoothly with the software and hardware out in the fleet. This would be essential for economic and efficiency reasons. For instance, the space onboard a carrier is very limited, and to require additional space for database equipment would not be practical.

In addition to the quantitative cost benefits, there are numerous qualitative factors that must be considered.

C. OTHER BENEFITS

1. Process Time

As detailed in the preceding subchapter, the present-day Naval Aviation maintenance scheduling method takes a considerable amount of time from the managers' daily routine to perform. To a large degree, this has become a cultural norm, where most maintenance managers consider this manual daily planning and scheduling process as a necessary evil. However, the authors believe that this time is a manager's resource to which there is a opportunity cost. This opportunity cost could potentially make the maintenance managers and the entire organization more productive if many of the labor-intensive scheduling tasks could be performed by someone or something else.

In view of the greatly reduced process time required to generate and regenerate maintenance schedules, the integration of an automated DSS, similar to DockPlan, into the NALCOMIS maintenance database, as several large commercial airlines have done, could potentially improve the productivity of the squadron's entire maintenance department. This would be due primarily to the ability of the MMCO and the MMCPO to have ample time to look at alternative scheduling plans, iteratively generated by the automated DSS, and to take action on whichever plan they deem the most

optimum in terms of anticipated resources and what downstream effects their decisions would have on future maintenance actions.

2. Complexity

The issue of system complexity concerning the current Naval Aviation maintenance scheduling method closely parallels the process time issue in terms of the numerous databases and numbers of personnel to construct and integrate the relevant maintenance information. The system presently in use attempts to integrate information from several sources; some have existed for many years, such as daily time sheets and Monthly Maintenance Plans, and only which have in the past decade been placed in a "computerized" format through the use of spreadsheets and word processing programs. Other maintenance databases have been created as systems external to the previously-used Maintenance Data System and current NALCOMIS system. For example, ECAMS, used in support of the FA-18 aircraft, was not designed to nor does it presently integrate with NALCOMIS, making manual reporting and integrating a long and tedious, but necessary, process. As long as ancillary databases are used which are external to the NALCOMIS architecture, the scheduling/planning process will remain very complex.

On the other hand, a commerically-available automated DSS, similar to DockPlan, properly integrated within the NALCOMIS architecture, can potentially eliminate many of the spreadsheet and word-processing databases used in the scheduling process by

providing a visual graphic capability that accurately reflects the maintenance schedule.

3. Training

In the comparison of current Naval Aviation and commerical airlines scheduling methods, it was pointed out that system complexity -- number of databases involved -- directly influences the amount of training required to master the system. Because the present-day scheduling method within Naval Aviation squadrons involves formatting and integrating information from four or more databases, each AZ must normally take three or four months of on-the-job training, eight to eleven percent of his or her total time in the squadron, just to become proficient with the tasks involved in manipulating the individual databases.

Additionally, as highlighted in Chapter III, different squadrons use different databases to provide the maintenance managers necessary information to make and adjust scheduling plans. This further complicates the training process, because what one AZ learns to perform in one squadron might not be the same tasks that he or she might perform in another squadron.

With a DSS integrated into the NALCOMIS architecture, as the commercial airlines' DSSs have integrated into their maintenance data systems, the variability from squadron to squadron should be greatly reduced. The need for training on additional databases would be eliminated; training on the automated DSS would be integral to the NALCOMIS training, thus saving training time and opportunity costs.

4. Flexibility and Adaptability

The analysis of flexibility and adaptability of the different types of scheduling systems are closely related because both issues are built around a focus of integration of information. The present-day Naval Aviation maintenance scheduling system does have the flexibility to readily integrate dynamic operational and maintenance changes into the overall maintenance plan. However, it takes a relatively long time to see how these changes affect the long-range maintenance schedule.

Due to the fact that it is software-oriented, an automated DSS should be able to be integrated into the NALCOMIS system to directly read maintenance data from the LMDSS database. This would afford the maintenance managers the same amount of flexibility and greater speed in generating maintenance schedules. The operational requirements could be manually integrated into the system, which would not be very time consuming due to the fact that there are limited variables involved.

In terms of adaptability, the current Naval Aviation maintenance scheduling system is more adaptable to different type/model/series than the automated stand-alone DSS which the authors tested for short-term planning. It also is capable of being deployed anywhere with or without the support of the NALCOMIS system through the use of handwritten VIDS/MAFS. The only negative adaptability aspect of NALCOMIS is its inability to assimilate information concerning engine and structural fatigue life data, which is not based on flight hours, cycles or calendar days.

In view of this constraint, an automated DSS integrated into NALCOMIS would possess the same problem, because it would only be able to access the information available throught the LMDSS database. But, once the DSS is integrated with NALCOMIS, it would be adaptable to all weapon systems using the database. A non-integrated system, such as a non-resident DockPlan system as the authors tested, requires intensive manual manipulation of maintenance data into the software, and, therefore, is not as adaptable as present-day systems.

5. Communications

As addressed in Chapter III, the lack of real-time updates and the various output formats of maintenance schedules that exists in today's Naval Aviation maintenance scheduling system complicates effective communications of plans and intents between the various interested parties. This tends to impede effective management because of the interdependencies that exist between the interested parties, for example, the Maintenance and Operations Departments. Miscommunications between these two parties could potentially result in improperly configured aircraft for a mission or insufficient numbers of aircraft to meet a flight schedule. This would cause the Maintenance Department to either resort to crisis management to solve the problem at hand to make the mission, or, less desirably, cause the Operations Department to cancel the mission. Both instances hold the potential for minimizing lost opportunities if communications could be improved.

If an automated DSS could be integrated into NALCOMIS, all information could be fairly close to real-time and would be accessible to all interested parties. By using a Gantt-type graphic display, similar to that utilized in DockPlan, any party would receive the same information available to the others for both the short- and long-term schedules. This would make communications more effective and minimize the potential for lost opportunities.

6. Long-term Strategic Planning

Because many Naval Aviation squadrons focus their scheduling and preparation efforts on the next operational commitment, they tend not to spend much time visualizing and examining what future consequences that their immediate decisions have on the maintenance, and possibly, the operational schedule. In turn, this tendency to focus on minimizing resources, defined as time, parts and personnel, in the short term might have a more negative effect in the future where one or more of these resources might be more critical to completing the mission. Without the ability or the motivation to plan out six to nine months in advance, maintenance managers potentially can make "off-the-cuff" decisions without knowing the effects of their decisions during deployed operations.

With an automated DSS that attempts to optimize the maintenance schedule within operational and programmatic constraints (already integrated within the software), maintenance managers in any squadron would have the ability to find the "best" available solution for their maintenance schedule by balancing operational and maintenance requirements with a long-term focus.

This would also enable them to examine the long-term effects on time, personnel and parts.

7. Aircraft Utilization and Readiness

Most of all, the present-day Naval Aviation maintenance scheduling system attempts to maximize aircraft availability and readiness by utilizing a large amount of personnel working long hours, sometimes entailing extended or extra shifts, to produce enough aircraft to meet upcoming operational commitments. This tends to be scheduled in a relatively haphazard manner and fails to examine the opportunity costs of personnel, parts, and time, as well as trying to minimize the variability of similar maintenance processes. Additionally, very little tangible incentives are presented to squadron maintenance managers to attempt to radically improve aircraft utilization.

If an automated DSS can improve long-term aircraft utilization by nearly 20 percent for a commercial airlines, where the motivation is company profit, then there should be a commensurate increase in Naval Aircraft availability if an automated DSS can be integrated into NALCOMIS and become part of the daily scheduling routine. In addition, as long-term availability and, in turn, readiness, would increase, the optimization function of the DSS would also lead to better use of personnel, parts and time over the long run as well. A more effective and tangible incentive, along with a more efficient means of measuring utilization and readiness, would have to be implemented for the maintenance managers to improve utilization and readiness if dramatically positive results are to be realized.

V. IMPLEMENTATION

A. INTRODUCTION

If and when an automated DSS is integrated into Naval Aviation maintenance management, the success of the system's implementation plan would prove to be the determining factor to the potential effectiveness of the maintenance scheduling process.

Planned fleet implementation would occur in 3 phases:

(i) development
(ii) initial prototype operational test
(iii) full deployment

Each phase would focus on goals and objectives based on the following factors:

1. management and staff personnel utilization
2. process time
3. flexibility
4. adaptability
5. maintenance/inspection yield
6. aircraft utilization
7. mission readiness

Satisfactory completion of each phase would require management approval prior to the start of the next phase. By using

an incremental strategy, progress on key items can be tracked effectively while lessening the impact on the entire fleet's way of doing business. The next three sections will describe, in detail, these three phases.

B. DEVELOPMENT PHASE

Even though technologically mature, commercial off-the-shelf DSS systems, such as DockPlan, exist and can be modified to meet the needs of Naval Aviation, the development phase of this DSS remains the most crucial for the system's success. Key elements that must be considered during this phase are: an improved and efficient management scheduling tool; a design architecture to meet the requirements of the customers; smooth integration with current data systems, including software and hardware; an effective training program; a long-term support program; and a life cycle cost plan that stays within budgetary constraints.

To oversee the implementation process, a Fleet Design and Implementation Team (FDIT) must be formed. In order to represent the needs, expectations and abilities of squadron users, the team should include former aviation maintenance managers (MMCOs and MMCPOs) who come from various aircraft type backgrounds, as well as technical representatives from Naval Space Warfare Systems Command (SPAWAR), NAVMASSO and the contractors for both NALCOMIS and the DSS.

Any system which is procured and intended to be used with the existing and projected maintenance data systems, in this case,

NALCOMIS, must provide a perception to the user of being "seamlessly integrated" into the maintenance data system. This automated DSS, similar to DockPlan, would be capable of accessing all applicable historical maintenance data from the LMDSS database through the NALCOMIS architecture. It would need to be an integral part of the existing NALCOMIS organizational-level system, not a stand-alone system, so that it can potentially be more user-friendly and eliminate the need for acquiring, sustaining and training on a new system.

Accessible data would include previous inspection base dates and cycles; current aircraft/component times and cycles; and component installation times or cycles, all which are tracked within the LMDSS database. These would enable the DSS to optimize a future maintenance scheduling plan for each squadron.

The automated DSS would need to reflect scheduling information in a Gantt-type chart format, similar to DockPlan. Each line entry in the chart would be assigned to each aircraft in the squadron, showing both the aircraft's bureau number and modex (local side number). The visible scheduling horizon could for instance, show four weeks from the present date, with the ability to schedule out to three years in advance. This enables the maintenance managers to better visualize multiple maintenance inspections which can be performed concurrently (i.e.,7-, 14-, 28-, and 56-day inspections).

Additionally, the system would need some symbology, similar to the "pucks" in DockPlan, that would identify the maintenance and

operational requirements for each aircraft. These symbols, capable of being positioned automatically or manually, would reflect not only that the aircraft is required for an inspection or mission, but also the type and time length required. A pull-down menu to reveal more specific aircraft information, such as weapons and systems configuration, fuel loading and any other relevant items, would provide the kind of information a squadron MMCO or MMCPO need to effectively assign resources. Lastly, the system must also contain some growth potential to allow for new constraints to be included in the program or future product improvements.

Since the maintenance inspection processes would theoretically become more optimized in terms of maximizing time between required inspections, a new and more efficient metric, which the authors identify as maintenance/inspection yield, would be needed to properly measure this efficiency term. This concept is similar to the maintenance check yield or "green time" which is used by American and United Airlines, respectively, as discussed in Chapter II.

During this phase, an effective training program must be developed, reviewed and integrated into the current NALCOMIS training syllabus taught at various fleet locations for aviation maintenance managers and administrative staff. This training block would focus on use of the DSS and how to configure reports. In addition, the Aviation Maintenance Officers Course, which all new Aerospace Maintenance Duty Officers and the majority of aviation

Warrant and Limited Duty Officers attend, can include this same DSS training block into its syllabus.

A Test and Evaluation Master Plan (TEMP) would also be formulated and promulgated prior to the end of the development phase. Specific goals and objectives would be outlined and disseminated so they could be clearly understood by all participants in the initial prototype/operational test phase.

C. INITIAL PROTOTYPE/OPERATIONAL TEST PHASE

Operational testing of the integrated DSS system would consist of placing the initial system with one squadron per aircraft type. This would enable evaluators from the FDIT to identify specific integration problem areas for each type and model of aircraft. It also would provide a contrast between the two scheduling methods, as the other squadrons without the DSS would provide a control group for better comparison. The length of these test would be over one full workup and deployment cycle, normally about eighteen months. Parameters identified in the introduction paragraph would be measured during this prototyping period.

Also, technical representatives from the contractor and Navy organizations would be on site during the prototype and test phase. These representatives would present the test findings to a joint NAVAIR/SPAWAR command review board before commencement of the deployment phase.

D. DEPLOYMENT PHASE

Once the DSS system has proven to be operationally effective and supportable, fleet implementation would commence with incremental outfitting of all Naval Aviation squadrons. Each type commander would incorporate all squadrons within an air wing soon after they return from their six-month deployments as they begin their training cycle for the next deployment.

Initial system installation would be performed by trained Navy and/or contractor representatives. Squadron personnel would receive initial DSS training as a group, using the NALCOMIS DSS module syllabus, by Navy or contractor instructors at existing NALCOMIS training sites, or by sending field teams to the homebase locations.

A continuous feedback system, similar to the problem reporting system used during NALCOMIS implementation, would be available to the customers so any emergent problems that occur could be resolved quickly, and trend analysis could be initiated to track recurring program and technical problems. In turn, this would reduce possible frustrations that will invariably occur during the initial operations of the DSS. After the initial development phase is completed, management should receive their DSS training as addressed previously.

With this automated DSS system integrated into the NALCOMIS architecture, maintenance managers would not only strive to attain standardized readiness, availability and productivity objectives, but also, in the quest for continual improvement, be able to achieve

higher goals as they become more proficient in scheduling maintenance functions. In order to provide proper impetus for Naval Aviation maintenance managers to continue to improve their outputs, the Navy would have to implement more effective incentives to encourage improvement on objectives. Rather than a squadron receiving only local recognition for meeting availability and readiness goals (i.e., wing-sponsored "Golden Wrench" awards), possibly more tangible awards could be presented to the maintenance department when they achieve a certain incremental increase in availability, readiness and productivity over a sustained period of time, such as an eighteen-month workup and deployment cycle.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

This thesis focuses on the influences that an automated DSS would have on the organizational-level maintenance management processes within Naval Aviation squadrons. The authors studied the potential effects of this system in regards to manpower, time, aircraft and overall mission readiness. Two types of Naval Aviation squadrons, FA-18C and P-3C, and two major commercial airlines, American and United, were examined in this study. Although some differences in measurement systems exist, many commonalities were inherent in both systems; the authors strived to maintain a high level of objectivity in examining both scheduling practices by interviewing a wide variety of maintenance management personnel.

Even though different environmental factors, such as aircraft flight time, mission profiles and maintenance technicians, vary greatly between commercial airlines and Naval Aviation squadrons, both organizations attempt to optimize aircraft utilization, mission readiness and/or maintenance yield under constrained resources in order to meet operational commitments. Because of dynamic constraints and environmental factors, changes in maintenance schedules must be performed on a continuing, iterative basis, requiring integration of numerous maintenance databases and intensive number crunching.

In order to take advantage of the speed and efficiency related

to automated software systems, a few commercial airlines have recently developed and implemented integrated DSS systems within their maintenance information systems. This enables them to perform “what if” analysis on maintenance schedules due to the changing constraints and commitments, while making extraordinary improvements in management and worker productivity. At the same time, these airlines are increasing their overall aircraft utilization and management yield (green time). As stated by a senior planning analyst with United Airlines, “our constrained resources are manpower, facilities, and airplane utilization. A DSS system allows us to determine how to best optimize these resources based on the current constraints within the environment at that time” (McLain, 1995).

Opportunities for improved utilization of manpower, repair facilities, and aircraft in commercial airlines have justified the development and/or procurement of an automated DSS. The authors have determined that the same practices of maintenance scheduling used by commercial airlines will significantly reduce the major cost drivers that attribute to the Navy’s variabilities in aircraft availability and manpower planning.

B. CONCLUSIONS

From this study, the authors have found that the foundations for Naval Aviation and commercial aviation preventive maintenance scheduling procedures are very similar, but the methodology used by each business differs markedly due to the commercial airlines’

emphasis on automating calculation and optimizing tasks. For example, American Airlines' DockPlan greatly reduced the required manhours previously needed to produce a long-term maintenance schedule. More importantly, it improved the overall utilization of maintenance resources and aircraft availability.

The DSS purchase price relative to the opportunity and actual cost savings was minimal. The long-term benefits were very apparent, especially in relationship to manpower and aircraft utilization. The Navy's relative potential cost savings, at only the organizational-level, greatly outweighed the projected initial start-up costs. The annual opportunity cost savings and initial start-up costs for each squadron are estimated to be $39,000 and $50,000, respectively, at the implementation level of 21 to 35 squadrons. For the Naval Aviation fleet of approximately 250 squadrons, initial investment costs would vary with the economies of scale and the type of system purchased. However, by multiplying the estimated opportunity cost savings and initial start-up costs by 250, the annual opportunity cost savings and the total initial installation cost for the fleet could potentially be $9,750,000 and 12,500,000 respectively. Since the maintenance costs are expeced to be minimal, a breakeven point would be achieved during the second year of implementation.

C. RECOMMENDATIONS

In order to better deal with increasingly constrained resources and changing operational requirements, as well as to take advantage of the significant progress in DSS automation, the authors recommend

that the Navy procure and implement an automated DSS and integrate it into the NALCOMIS maintenance information system. To reduce lead time and minimize development risk and cost, a viable option would be to take a commercial off-the-shelf aviation-related DSS system and modify it to meet the needs of organizational-level activities. This recommendation is only suggested if the program can be formatted to fit into the Navy's environment. Although it is not suggested nor is it immediately necessary that the Navy radically change its maintenance practices to fit the commercial practices, possible improvements in metrics as highlighted in Chapter V could be incorporated in the future. If this system becomes a reality, then all new aviation weapon systems would be developed to function with the Navy's current DSS. Without the uniformity introduced by this integrated system, the Navy would lose some of the benefits it would derive from the DSS. The primary focus to keep in mind while developing a DSS for Navy use is that it maximizes the utility of resources, minimizes the impact of constraints and is easy to operate.

An automated DSS would be very practical in other military organizations beside aviation organizational-level maintenance. Some proposed areas for future research at the Naval Postgraduate School include:

1. Aviation depot-level maintenance
2. Shipyard overhaul and repair programs
3. Surface ship organic maintenance
4. Integration of manpower availability and skill levels into the NALCOMIS system

In this present and foreseen environment of limited resources,

the NAVAIR must look for the most efficient ways to accomplish the missions it is tasked to perform. Currently, Naval Aviation squadron maintenance departments are doing the best that they can with the management tools afforded them. However, working harder does not necessarily imply that it is better. If the Navy does not take advantage of present opportunities to use "state-of-the-art" management technologies to improve efficiency and readiness, then it cannot expect to realize its readiness and resource potentials.

APPENDIX. LIST OF NAVAL AVIATION ORGANIZATIONAL-LEVEL MAINTENANCE PROGRAMS

Analytical Maintenance
Personal Qualification Standards
Fuel Surveillance
Certification and Licensing
Oil Analysis
Non-Destructive Inspection
Hydraulic Contamination Control
Nitrogen Servicing Equipment Surveillance
Tire and Wheel Maintenance and Safety
Weight and Balance
Foreign Object Damage
Tool Control
Corrosion Prevention and Control
Avionics Corrosion Prevention and Control
Aircraft Receipt and Transfer
Configuration Management
Special Interest Aircraft
Cannibalization Control
Component Preservation, Shipment and Storage
Hearing Conservation
Sight Conservation
Ordnance Handling
Hazards of Electromagnetic Radiation to Ordnance
Support Equipment
Material Issue Priority System
Flight Packets
Aircraft Inventory Records
Aeronautical Equipment Service Records
Aircraft Inventory Reporting System
Aircraft Engine Accounting System
Compass Calibration

Aircraft Armament Equipment
Battle Damage Repair
3-M Reporting
Aviators Breathing Oxygen Surveillance and Contamination (CNO, Volume I)

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